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(54) Air-to-fuel ratio sensor for an automobile.

(57) An air-to-fuel ratio sensor comprising a detecting part constituted by a zirconia solid electrolyte, (20) a first electrode (22) formed on the atmosphere side of said solid electrolyte, a second electrode (23) formed on the exhaust side of said solid electrolyte and a diffusion-resistant body (24) formed on said second electrode and a driving circuit (29) which drives said detecting part, wherein an electric potential of said second electrode is predetermined to be higher than a ground level (26) of said driving circuit and an exciting voltage is subjected to feed-back control by said driving circuit. (29)

FIG. 1

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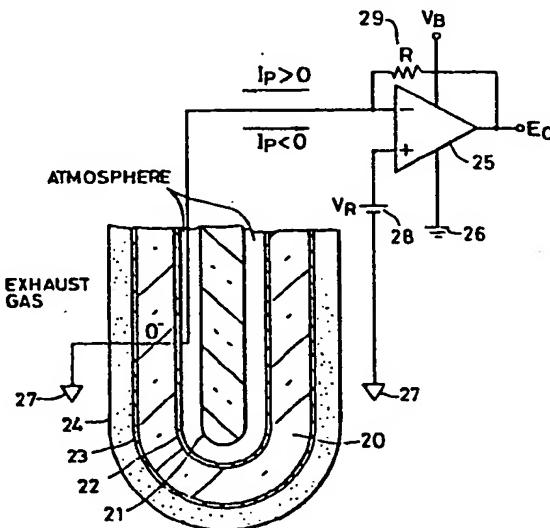
Specification

1   Title of the Invention:

Air-to-fuel ratio Sensor for an Automobile

(Field of   the Invention)

5   The present invention relates to a sensor for
an A/F control apparatus of an internal combustion
engine and, more particularly an A/F sensor for an
automobile which facilitates detecting A/F in three
conditions, a rich region, theoretical A/F and a
10   lean region, in a wide range.

(Background of the Invention)

It is desirable that an internal combustion
engine be operated in a rich region in which an excess
air rate λ is $\lambda < 1$, at $\lambda = 1$ (a theoretical A/F)
15   and in a lean region in which $\lambda < 1$ corresponding to
the conditions of the engine; hence it is required
that the A/F be detected in a wide range from the rich
region to the lean region by a single sensor.

On the other hand, relations between the excess
20   air rate λ and a residual oxygen consistency and a
carbon monoxide consistency in exhaust gas are as
shown in Fig. 11 and in the lean region the oxygen
(O_2) consistency varies approximately linearly to
the A/F and in the rich region the carbon monoxide
25   (CO) consistency varies approximately linearly to
the A/F.

Basic principles of A/F sensors of the prior

1　art which detect the A/F of each region individually

by utilizing the residual oxygen consistency and the

carbon monoxide consistency are shown in Fig. 12 (A)

$\sim$ (C). The A/F sensor is constituted by an electrode

5　1, a zirconia solid electrolyte 2, an electrode 3,

a protecting film 4 and an ammeter 5.

The sensor shown in Fig. 12 (A) detects the

rich region (λ < 1) by applying an exciting voltage

E of approximately 0.5 V between the electrode 1 and

10　the electrode 3 which are a cathode and an anode

respectively as known from, for instance, Japanese

Patent Laid-Open No. 66292/1978. The protecting film

4 functions as a gas diffusion resistant body and

the oxygen gas which is subjected to burning reaction

15　with unburnt gas which is diffused into the electrode

3 part through the protecting film 4 is transferred

from the electrode 1 part contacting the atmosphere

to the electrode 3 part through the zirconia solid

electrolyte 2 in the form of oxygen ions. Therefore,

20　a pumping current Ip measured by the ammeter 5 rep-

resents the quantity of the oxygen ions transferred

from the electrode 1 to the electrode 3 and corresponds

to the quantity of the unburnt gas diffused into the

electrode 3 part through the protecting film 4 so

25　that the analog detection of the A/F in the rich

region in facilitated by measurement of Ip.

As shown in Fig. 12 (B), when an electromotive

force e_λ between two electrodes is detected with the

potential of the electrode 3 contacting the exhaust

1   gas through the protecting film as reference, because

the value of e_λ changes incrementally by approximately

i V at the theoretical F/N, the approximate digital

detection of $\lambda = 1$ is facilitated by measurement of

5   e_λ. This principle is known from, for instance,

Japanese Patent Laid-Open No. 37599/1972.

As shown in Fig. 13 (C), when an exciting voltage

of approximately 0.5 V is applied between two electrodes

with the electrode 3 as a cathode, the oxygen ions

10 are pumped from the electrode 3 part to the electrode

1 part and the pumping current Ip is measured by the

ammeter 5. As this pumping current Ip corresponds

to the quantity of the oxygen diffused into the electrode

3 part through the protecting film, the lean region

15 $(\lambda > 1)$ can be detected from the Ip value. This

principle is known from, for instance, Japanese

Patent Laid-Open No. 69690/1977.

Examples of the characteristics of the sensors

of the prior art shown in Fig. (A) $\sim$ (C) are shown

20 in Fig. 13. The characteristic in the lean region

is shown by a one-dot-chain line, the characteristic

in the rich region is shown by a dotted line and the

characteristic at the theoretical A/F is shown by a

solid line. Thus the detection methods which can

25 detect individual regions are known but the constitu-

tion with which the A/F is detected smoothly in the

wide range by a single method is not proposed yet.

Note that, as the principle of the sensor shown

in Fig. 12 (B) is not based upon the speed of diffusion

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1   rule, the rate of the gas diffusion resistance of the

protecting film 4 of the sensor of Fig. (B) is formed

to be smaller than those of the sensors of Fig. (A)

and (C). In general, the thickness of the protecting

5   film 4 in the case of Fig. 12 (B) is formed thinner

than those in other cases.

It is also known from, for instance, Japanese

Patent Laid-Open No. 62349/1980 and Japanese Patent

Laid-Open No. 154450/1980 that analog detection of

10 . A/F can be obtained from a terminal voltage between

two electrodes by applying a certain current between

the electrodes and it is also shown that the A/Fs

in the rich region and the lean region can be detected

by switching the polarities of two electrodes. How-

15   ever, it is not shown when and how the polarities

must be switched.

It is also known from Japanese Patent Laid-

Open No. 48749/1983 that the theoretical A/F and the

A/F in the lean region can be detected by switching

20   the connection between two electrodes and an electronic

circuit and changing the measurement mode of the

sensor. However, detection in the rich region is not

considered in this method.

(Object of the Invention)

25   It is an object of the present invention to pro-

vide an A/F sensor for an automobile by which the

A/F in a rich region, the A/F at a theoretical A/F

in a lean region can be detected with a simple con-

stitution and high accuracy.

1   (Summary of the Invention)

In an A/F sensor of the present invention, an
electrical potential of an electrode provided on the
exhaust side of a zirconia solid electrolyte compos-
5 ing a detecting part is predetermined at the level
higher than the ground level of a driving circuit
which drives the detecting part and an exciting voltage
between an electrode on the atmosphere side and the
electrode on the exhaust side constituting the de-
10 tecting part is subjected to feed-back control by the
driving circuit. With this constitution, the A/F in
a rich region, at a theoretical A/F and in a lean
region can be detected continuously from quantity
of oxygen flowing through the zirconia solid electrolyte.
15 Brief Description of the Drawings:

Fig. 1 shows a principle constitution of an A/F
sensor of the present invention;

Fig. 2 is an electromotive force characteristic
diagram describing the principle of the present
20 invention;

Fig. 3 shows a circuit configuration describing
one embodiment of an A/F sensor of the presnet in-
vention;

Fig. 4 shows examples of characteristics of an
25 A/F sensor of the present invention;

Fig. 5 shows examples of V-I characteristics;

Fig. 6 shows the other embodiment of an A/F
sensor of the present invention;

Fig. 7 and Fig. 8 show still other embodiments

1   of an A/F sensor of the present invention;

     Fig. 9 shows an example of the other characteristic

of an A/F sensor of the present invention;

     Fig. 10 shows a circuit configuration describing

5   the other embodiment of an A/F sensor of the present

invention;

     Fig. 11 shows relations between A/F and exhaust

gas consistencies;

     Fig. 12 describes a principle of an A/F sensor

10   of the prior art;

     Fig. 13 describes characteristics of an A/F sensor

of the prior art; and

     Fig. 14 shows mounting state of an A/F sensor

of the present invention.

15   (Preferred embodiments of the Invention)

     Embodiments of an A/F sensor of the present in-

vention will be hereinunder described with reference

to related drawings.

     Fig. 14 shows the mounting state of an A/F sensor

20   of the present invention. A tubular detecting part

10 is provided in a protecting tube 12 which has holes

11 and fixed in a peg 14 and mounted in an exhaust

pipe 15 through which exhaust gas is flowing. The

reference numeral 16 denotes electrode terminals and

25   the reference numeral 17 denotes heater terminals

through which the detecting part 10 is connected to

an electronic circuit (not shown). A rod shape heater

(such as a tungsten heater mounted in an alumina rod)

is mounted in a zirconia solid electrolyte 10 compos-

1 ing a tubular detecting part.

Before describing the embodiments of the present invention, the basic principle of the present invention will be described hereinuder with reference to

5 Fig. 1 and Fig. 2.

A predetermined voltage V_E (for instance 0.45 V) is applied between an electrode on the atmosphere side and an electrode on the exhaust side regardless of an excess air rate λ such as shown by an exciting

10 voltage characteristic (b) in Fig. 2 against a characteristic of a curve (a) which changes incrementally at the theoretical A/F ($\lambda = 1$). With this applied voltage, an electromotive force of the curve (a) is decreased in a rich region ($\lambda < 1$) and is increased

15 in a lean region ($\lambda > 1$). The voltage V_E can be applied with a predetermined inclination as shown by characteristic (c) or incrementally as shown by characteristic (b).

Fig. 1 shows a principle constitution of the

20 present invention. The sensor of Fig. 1 is constituted by a detecting part of oxygen consitutuency and a driving circuit which drives the detecting part. The reference numeral 20 denotes a tubular zirconia solid electrolyte and the atmospheric air is introduced

25 into the electrolyte 20. The reference numeral 21 denotes a rod-shaped heater which heats the zirconia solid electrolyte 20 to at least 600°C to improve conductiveness of oxygen ions. A first electrode 22 is formed on the atmosphere side of the zirconia

1   solid electrolyte 20 and a second electrode 23 is

formed on the exhaust side of the zirconia solid

electrolyte 20. These electrodes are composed of

platinum with thickness of several tens of μm and

5   made porous. A diffusion-resistant body 24 is formed

on the surface of the second electrode 23 to suppress

gases such as oxygen or carbon monoxide which flow

from the exhaust gas atmosphere into the electrode

23 part by diffusion. The diffusion-resistant body

10 24 is formed by plasma spray from a spinner or the

like and made porous. In order to make diffusion

resistance rate large, the thickness of the diffusion

resistant body 24 is several hundreds of μm and has a

thickness several times that of the film in a theoretical

15 A/F sensor. The detecting part of the A/F sensor

is constituted as described above.

The reference numeral 25 denotes a differential

amplifier. The second electrode 23 is connected to

a floating ground 27 which has a level higher by a

20 certain voltage than a real ground 26. The first

electrode 22 is connected to a (-) side input terminal

of the amplifier 25. A voltage source 28 for pre-

determination of an exciting voltage V_R is inserted

between a (+) side input terminal of the amplifier

25 25 and the floating ground 27. A fixed resistor 29

of resistance R is provided for converting an oxygen

pumping current Ip which represents the quantity of

oxygen ions flowing through the zirconia solid electro-

lyte 20 into an output voltage Eo. The driving cir-

cuit of the A/F sensor is constituted as described above.

The operation of the A/F sensor of the present invention is hereinunder described.

As a potential of the second electrode 23 is lower than a potential of the first electrode 22 by V_R in the lean region, oxygen molecules in the second electrode 23 part are converted into oxygen ions (O^{--}) in the electrode part by the exciting voltage V_R and transferred to the first electrode 22 part through the zirconia solid electrolyte 20 by an operation of oxygen pump. Then the oxygen ions are again neutralized in the electrode part and discharged into the atmosphere. At that time, a positive pump current Ip (reverse direction to O^{--} flow) is applied in the circuit and the output voltage Eo is changed.

As the pumping current Ip, wherein Ip > 0, corresponds to the quantity of oxygen flowing from the exhaust gas atmosphere into the second electrode 23 part through the diffusion resistant body 24 by diffusion, the following equation is effected:

$$Ip = K(\lambda - 1) \qquad \ldots (1)$$

wherein λ is an excess air rate and K is a proportionality constant.

Therefore, if an electrical potential of the potential ground is Vo, as the output voltage Eo of the A/F sensor is,

$$Eo = V_R + Vo + IpR \qquad \ldots (2)$$

then from equations (1) and (2),

$$E_o = V_R + V_o + K(\lambda - 1)R \qquad \ldots (3)$$

At the theoretical A/F ($\lambda = 1$), the ratio of
the residual oxygen and the residual unburnt gas such
as carbon monoxide in the exhaust gas flowing into
the second electrode 23 part through the diffusion
resistant body is the ratio of the chemical equivalents
and both of them are completely burnt by catalysis
of the second electrode. As the oxygen is eliminated
in the second electrode 23 part, even if a voltage
is applied between the first electrode 22 and the
second electrode 23, no oxygen ion is transferred
through the zirconia solid electrolyte 20. Therefore,
the pumping current in the electronic circuit becomes
zero ($I_p = 0$).

1   At that time, from the equation (3), the output

voltage Eo is,

        Eo = V_R + Vo   ...(4)

which is a constant value determined only by circuit

5   constants. As the equation (4) is independent of

Ip, the output voltage Eo at λ = 1 is a highly reliable

value.

        In the rich region, as the electromotive force

between two electrodes is reduced to the level of

10   the exciting voltage as described in Fig. 2, the oxygen

ions flow from the first electrode 22 part into the

second electrode 23 part through the zirconia solid

electrolyte 20, or flow in the opposite direction

to the case of the lean region. The oxygen ion flow

5   increases oxygen consistency in the second electrode

23 part. The oxygen ions are again neutralized in

the second electrode 23 part to be converted into

oxygen molecules and are burnt with the unburnt gas

such as carbon monoxide which flows the exhaust gas

0   atmosphere into the second electrode 23 part through

the diffusion resistant body 24.

        Therefore, the quantity of the oxygen ions trans-

ferred from the first electrode 22 part to the second

electrode 23 part through the zirconia solid electrolyte

5   20 corresponds to the quantity of the unburnt gas

1 flowing into the second electrode 23 part by diffusion. At that time, the pumping current in the electronic circuit is Ip < 0.

As there is a certain relation between the con-
5 sistency of the unburnt gas such as carbon monoxide and the excess air rate λ as shown in Fig. 11, equations (1) ~ (3) are effective in the rich region too, except that in the lean region, as $\lambda > 1$, then Ip > 0 and in the rich region, as $\lambda < 1$, then Ip < 0.

10 Then one embodiment of a driving circuit of an A/F sensor of the present invention is hereinunder described with reference to Fig. 3. The same parts as in Fig. 1 are denoted by the same reference numerals as in Fig. 1.

15 The second electrode 23 is connected to the potential ground 27 (point Y) and controlled at a constant potential Vo by an amplifier 30. The potential of the first electrode 22 is controlled to be (Vo + V_R) by an amplifier 25. Therefore, the potential
20 difference between the first electrode 22 and the second electrode 23, or the exciting voltage V_E is,

$$V_E = (Vo + V_R) - Vo = V_R \qquad \ldots (5)$$

and is controlled at a constant value regardless of the excess air rate λ.

25 In the lean region, the pumping current Ip flows

from a point X to the real ground 26 through the
resistor 29 → the zirconia solid electrolyte 20 →
the floating ground point Y → the amplifier 30.

In the rich region, the pumping current Ip flows
from the floating ground point Y to the real ground
26 through the zirconia solid electrolyte 20 → the
resistor 29 → the point X → the amplifier 25.

At the theoretical A/F (λ = 1), in the sensor
Ip = 0 as the principle, the output voltage Eo becomes
(V_R + Vo) as given by the equation (4).

Thus, with the embodiment of an A/F sensor of
the present invention three conditions, i. e. λ < 1,
λ = 1 and λ > 1 can be detected continuously without
switching the polarities between two electrodes and
with a single source circuit.

Examples of the results obtained by the measure-
ment with the constitution of the embodiment of the
present invention shown in Fig. 3 are shown in Fig.
4. Fig. 4 shows the measured results when Vo = 4.55
V and V_R = 0.45 V. As shown by a solid line in the
diagram, the A/F can be detected in the wide range
from the rich region to the lean region continuously.
It was also confirmed that the output voltage Eo at
the theoretical A/F (λ = 1) was Vo + V_R = 5 V which
was predicted from the principle.

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1   With this embodiment, the A/F in the whole re-

gions can be detected linearly and with high accuracy

and smooth feed-back control A/F is facilitated in

accordance with the conditions of an engine and a

5   far more excellent control system in terms of exhaust

gas countermeasure and fuel economy, compared to sys-

tems of the prior art, can be provided. Especially,

significant improvement of fuel efficiency can be

expected by that engine control in the lean region

10   is facilitated and that linear feed-back control in

the rich region is facilitated.

V-I characteristics of the sensor detecting part

are shown in Fig. 5.

As shown in the diagram, a pumping current Ip

15   shows a certain saturated value at a certain exciting

voltage. By measuring the saturated current value,

the excess air rate λ can be detected. If the excit-

ing voltage V_E goes higher, the pumping current Ip

shows a higher value than the saturated value. This

20   phenomenon is caused by a shift of the conduction

mechanism in the zirconia solid electrolyte 20 from

ion conduction to electron conduction. The smaller

the excess air rate, the lower the exciting voltage

V_E at which shift to the electron conduction occurs.

25   In the region of $\lambda > 1$, the pumping curent Ip > 0

and corresponds to the quantity of oxygen flowing
into the second electrode 23 part by diffusion through
the diffusion resistant body 24. In the region of
$\lambda < 1$, the pumping current Ip < 0 and corresponds to
the quantity of unburnt gas such as carbon monoxide
flowing into the second electrode 23 part by diffusion
through the diffusion resistant body 24. Fig. 5
shows V-I characteristics when the temperature Tg
of the zirconia solid electrolyte is 700°C.

If the saturated current Ip corresponding to
each excess air rate can be detected, the A/F can
be detected linearly in the wide range from the rich
region to the lean region. As understood from the
V-I characteristics shown in Fig. 5, these saturated
current values can be measured by predetermining the
characteristic (b), the characteristic (c) or the
characteristic (d) as the exciting voltage characteristic
to the excess air rate.

If the exciting voltage characteristic is (b),
measurement of the saturated current near $\lambda = 0.5$ and
$\lambda = 1.5$ is difficult. This problem is solved by con-
verting the exciting characteristic into (c), or pref-
erably (d).

As internal resistance of the zirconia solid
electrolyte increases when the temperature decreases,

the region of the V-I characteristic α becomes narrow. Therefore, measurement of the saturated current tends to be difficult at the low temperature. This tendency is the most noticeable with the characteristic (b). To solve the problem, the zirconia solid electrolyte must be heated to high temperature by a heater. It is recommended to heat the zirconia solid electrolyte with the heater to a temperature not less than approximately 750°C, 700°C and 670°C when the exciting voltage characteristic is (b), (c) and (d) respectively. Taking the power consumption and the durability of the heater into account, the characteristic (c) is preferred to (b) and (d) is preferred to (c).

These exciting voltage characteristics (b) (c) and (d) correspond to the characteristics (b) (c) and (d) shown in Fig. 2 respectively.

Fig. 6 shows one embodiment of the present invention with which the exciting voltage characteristic (c) shown in Fig. 2 is obtained, wherein a resistor 33 and resistor 34 are inserted between the source 28 and the point X of the configuration give by Fig. 3. As a result, a potential difference rIp is produced in the resistor 34 part in accordance with the output voltage Eo changed by the pumping current Ip and the

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potential difference between the first electrode 22
and the second electrode 23, or the exciting voltage
between two electrodes, is changed by this value.
If the resistance (r) of the resistor 34 is predeter-
mined to be close to the internal resistance of the
zirconia solid electrolyte 20, the output voltage
Eo of the A/F sensor is less influenced by the tem-
perature of the exhaust gas. As the potential dif-
ference rIp is changed not only by the resistance
(r) but also by the pumping current Ip, it is auto-
matically changed by the excess air rate λ and the
potential difference between two electrodes or the
exciting voltage V_E shows the characteristic (c) shown
in Fig. 2. With this constitution, temperature dependency
of the oxygen ion conduction rate in the zirconia
solid electrolyte is improved.

An embodiment other than shown in Fig. 6 is
shown in Fig. 7. An amplifier 280 has the same func-
tion as the source 28 in Fig. 3. With this circuit
configuration, even if the temperature Tg of the
zirconia solid electrolyte 20 is 650°C, the output
characteristic is identical to that of the solid line
in Fig. 4. Therefore, this configuration is also ef-
fective as a countermeasure against the influence of
temperature.

1   Fig. 8 shows one embodiment of the present in-
vention with which the exciting voltage characteristic
(d) shown in Fig. 2 is obtained, wherein basically
an amplifier 281 for addition and subtraction, a dual-

5   output comparator 41 and switches 42 and 43 are added
to the configuration of Fig. 7. The switches 42 and
43 are driven by output signals V and $\overline{V}$ of the dual-
output comparator 41 which are reversed at the instance
of the pumping current Ip = 0 and a voltage (v) is

10   supplied to a (+) side input terminal and a (-) side
input terminal of the amplifier 281 for addition and
subtraction alternately. Taking V* as a potential
at the (+) side input terminal part Z of the amplifier
25 and (i) as the current in the resistor 33 part.

15    $$V^* = Vo + V_R + v + ri \quad \text{at } \lambda > 1$$
$$V^* = Vo + V_R - v + ri \quad \text{at } \lambda < 1 \qquad \ldots(6)$$

With such circuit configuration, the exciting
voltage characteristic between two electrodes as given
by the characteristic (d) in Fig. 2 can be obtained.

20   Therefore, it is easily understood from the V-I char-
acteristics shown in Fig. 5 that this exciting voltage
characteristic (d) is suitable for detecting the
saturated pumping current Ip corresponding to each
excess air rate λ.

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One example of the obtained result measured by
the circuit configuration of Fig. 8 is shown in Fi.g
9. This diagram shows the measured result when v =
0.15 V. In this case, as shown in the diagram, the
output voltage Eo changes in step by 2 V at the
theoretical A/F, $\lambda = 1$.

The stepping change of 2V is not a substantial
problem in this embodiment and, if 2V is added to
the characteristic shown in Fig. 2 in the region of
$\lambda \leq 1$, the characteristic of the exciting voltage Eo
becomes linear in all regions.

With the constitution of this embodiment, an
effect can be obtained which limits the decline of
accuracy caused by the deterioration of the electrode
(increase of interfacial resistance).

It is to be noted that, although the form of
the zirconia solid electrolyte of the detecting part
of the A/F sensor is described as tubular in the above
description, it is not to be construed as limiting
the scope of the invention. In other words, any struc-
ture such as a flat plate type shown in Fig. 10 with
which the ambient atmosphere can be introduced into
the first electrode part may be accepted.

Fig. 10 shows a detecting part, wherein a zirconia
solid electrolyte is a flat plate and a diffusion

1 resistant body consists of, for instance, one hole.

In Fig. 10, the same reference numerals as in Fig. 1 denote the parts which have the same function as in Fig. 1. The atmospheric air is introduced into

5 the first electrode 22 part through a passage 32. Residual oxygen and unburnt gas in the exhaust gas flow into the second electrode 23 part in a diffusion chamber 31 by diffusion through a tubular diffusion-resistant body 24. The zirconia solid electrolyte

10 20 is heated and controlled to a high temperature (for instance 600°C) at which the oxygen ion conduction rate is high.

· (Effect of the Invention)

With the present invention, an A/F sensor which

15 can detect A/F in a wide range of three conditions, a rich region, theoretical A/F and a lean region, with a simple constitution and high accuracy can be provided.

20

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5   C L A I M S
          ───────────

10 1. An air-to-fuel ratio sensor, hereafter called an
        A/F sensor for an automobile, c h a r a c t e r i z e d
        b y   a detecting part constituted by a zirconia solid
        electrolyte (2,20), a first electrode (1,22) formed on
        the atmosphere side of said solid electrolyte (2,20), a
15   second electrode (3,23) formed on the exhaust side of
        said solid electrolyte (2,20) and a diffusion-resistant
        body (4,24) formed on said second electrode (3,23) and
        a driving circuit (25-29, 30,33,34,280,281,41-43) which
        drives said detecting part, wherein an electric poten-
20   tial of said second electrode (3,23) is predetermined
        to be higher than a ground level (26) of said driving
        circuit (25-29,30,33,34, 280,281,41-43) and an exciting
        voltage is subjected to feed-back control by said
        driving circuit (25-29,30,33,34,280,281,41-43).
25
    2. An A/F sensor for an automobile as claimed in claim 1,
        characterized in that an exciting voltage between said
        first electrode (1,22) and said second electrode (3,23)
        is controlled to be constant.
30
    3. An A/F sensor for an automobile as claimed in claim 1,
        characterized in that an exciting voltage between said
        first electrode (1,22) and said second electrode (3,23)
        is changed by feedback control in accordance with the
35   quantity of oxygen ions flowing through said solid
        electrolyte (2,20).

1 4. An A/F sensor for an automobile as claimed in claim 1,
    characterized in that an exciting voltage between said
    first electrode (1,22) and said second electrode (3,23)
    is changed in step form by feed-back control in accor-
5   dance with the direction of the flow of oxygen ions
    through said solid electrolyte (2,20).

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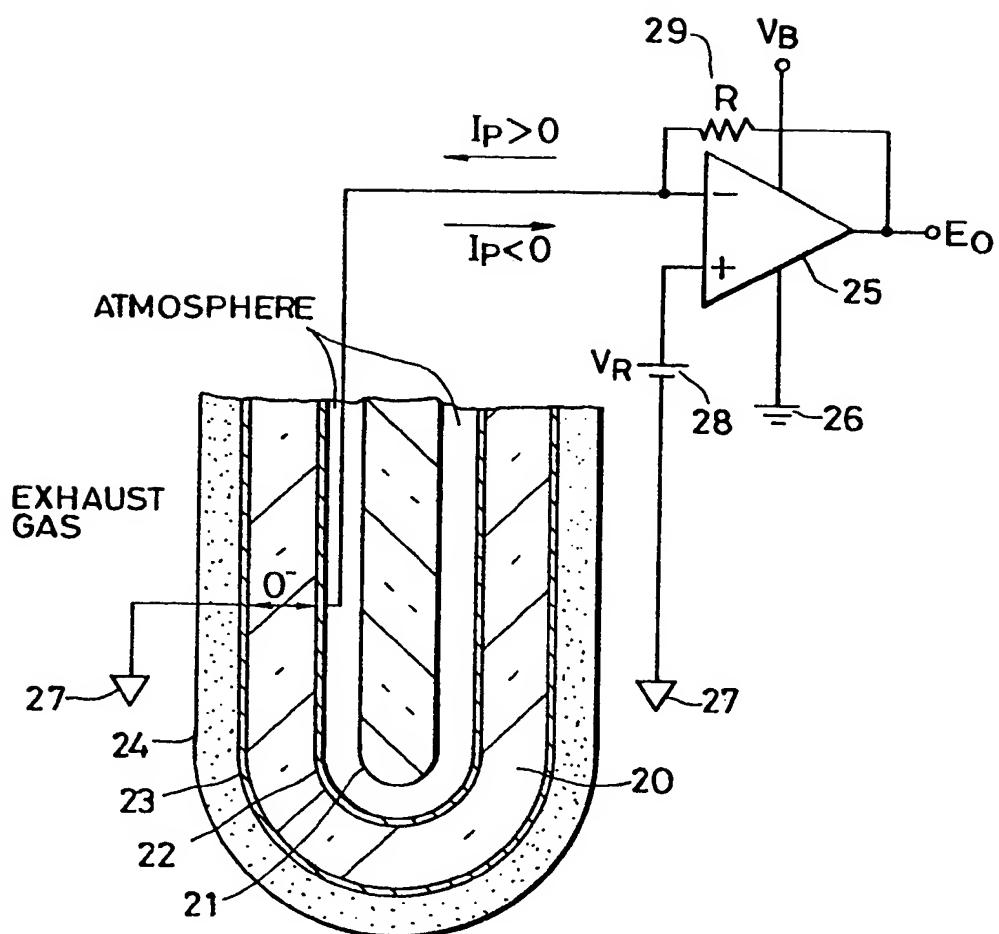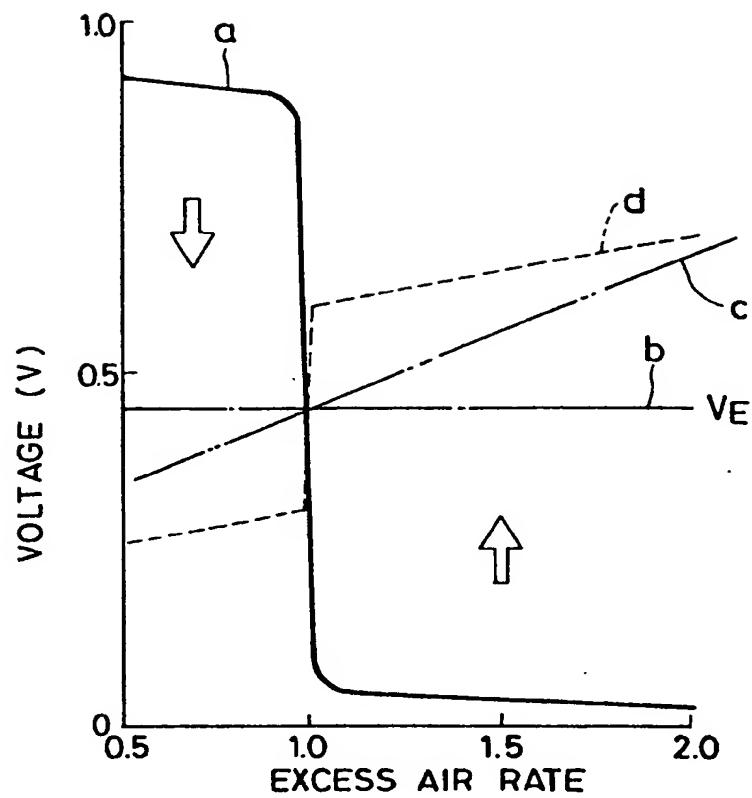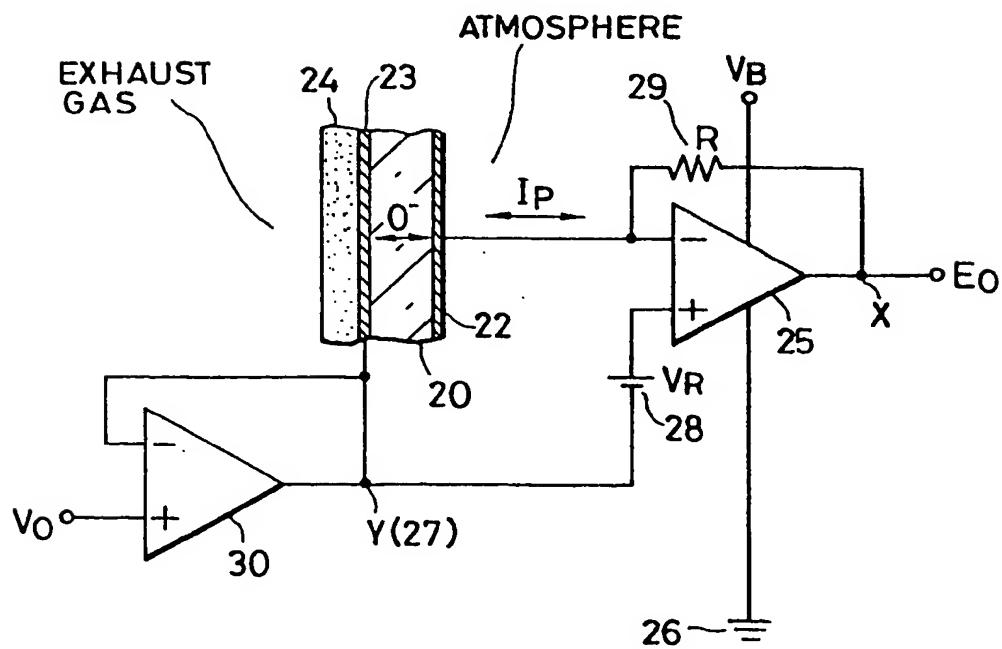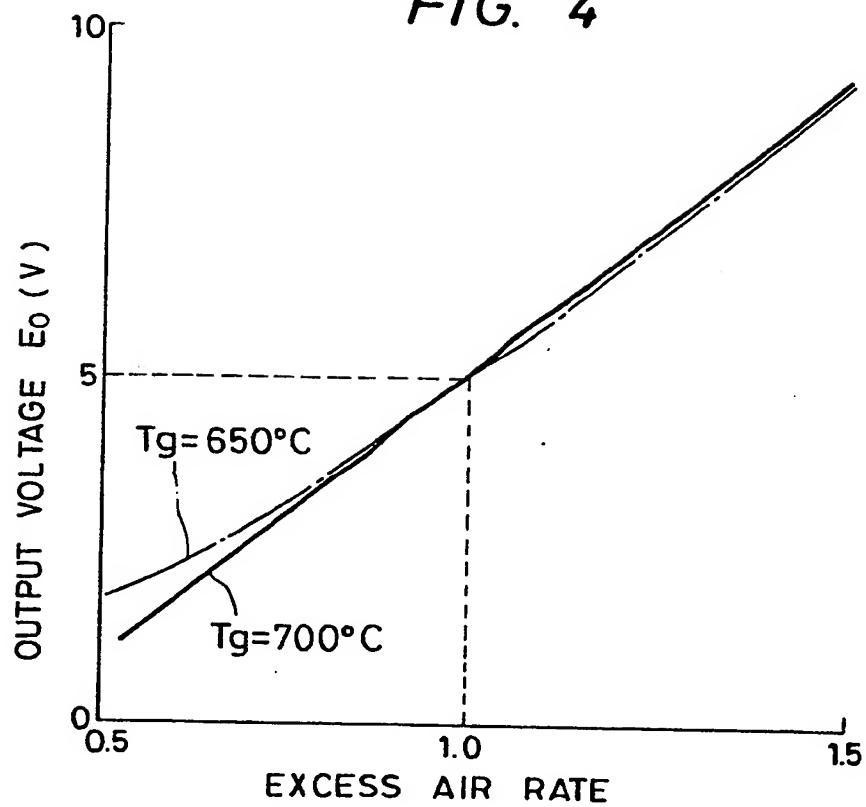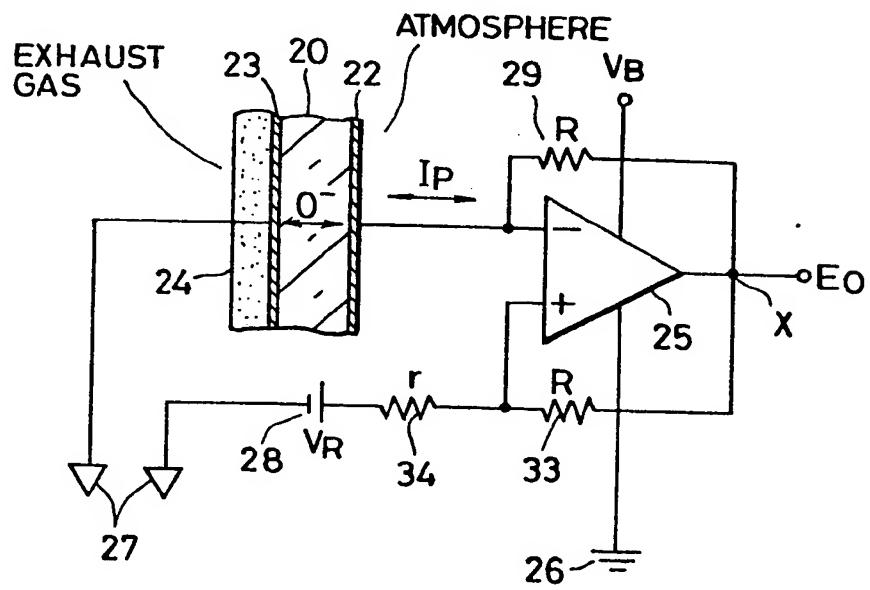
FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 6

FIG. 5

5/10

FIG. 7

6/10

FIG. 8

7/10

FIG. 9

FIG. 10

FIG. 13

ELECTROMOTIVE FORCE e_λ (V)

EXCESS AIR RATE

$\lambda > 1$

$\lambda = 1$

$\lambda < 1$

PUMPING CURRENT I_p (mA)

FIG. 11

EXCESS AIR RATE (λ)

THEORETICAL A/F

O2

LEAN REGION

A/F

CO

RICH REGION

CO, O2 (VOLUME %)

FIG. 12(A)

λ<1

E 5
IP

1 2 3 4

O⁻ ⟹

⟸ CO

ATMOSPHERE

EXHAUST GAS

FIG. 12(B)

λ=1

eλ

1 2 3 4

ATMOSPHERE

EXHAUST GAS

FIG. 12(C)

λ>1

E 5
IP

1 2 3 4

⟸ O⁻

⟸ O₂

ATMOSPHERE

EXHAUST GAS

10/10

FIG. 14

EXHAUST GAS
FLOW
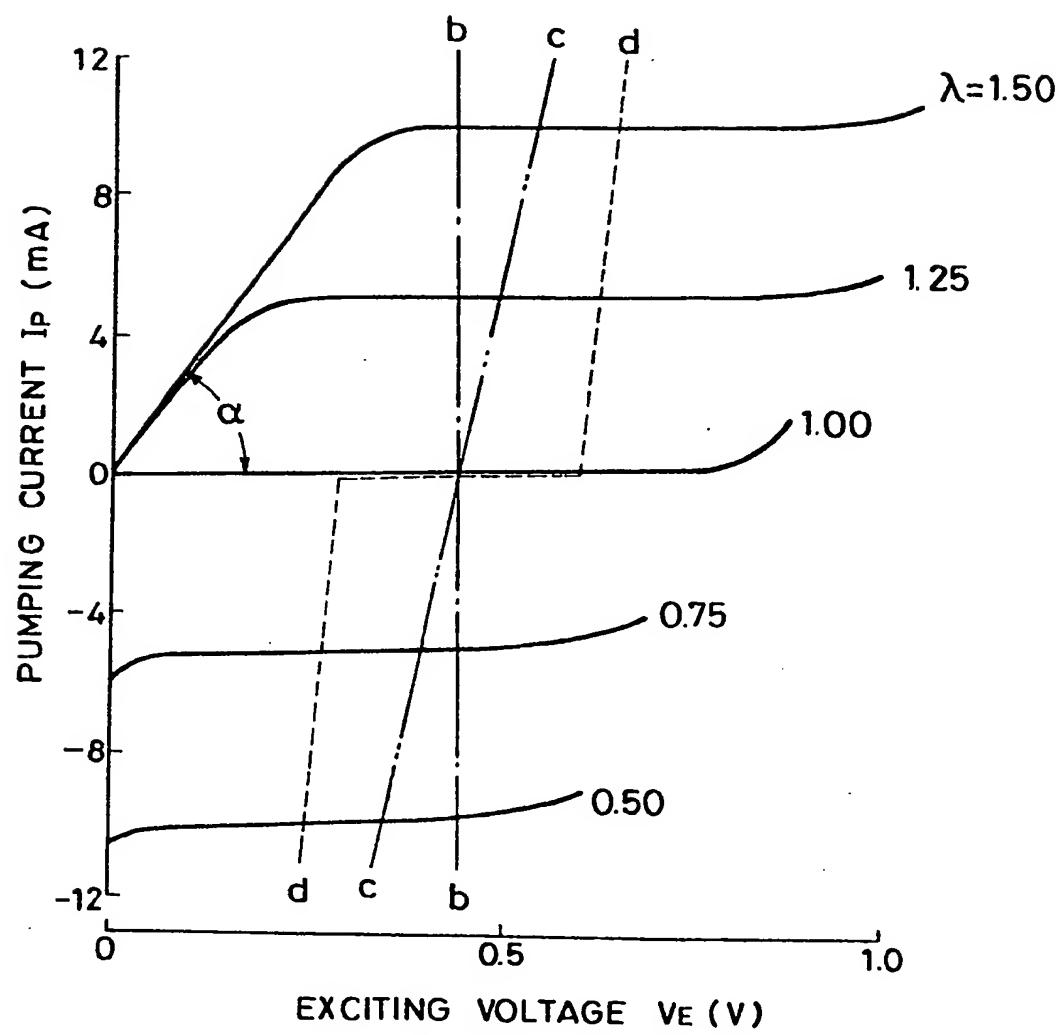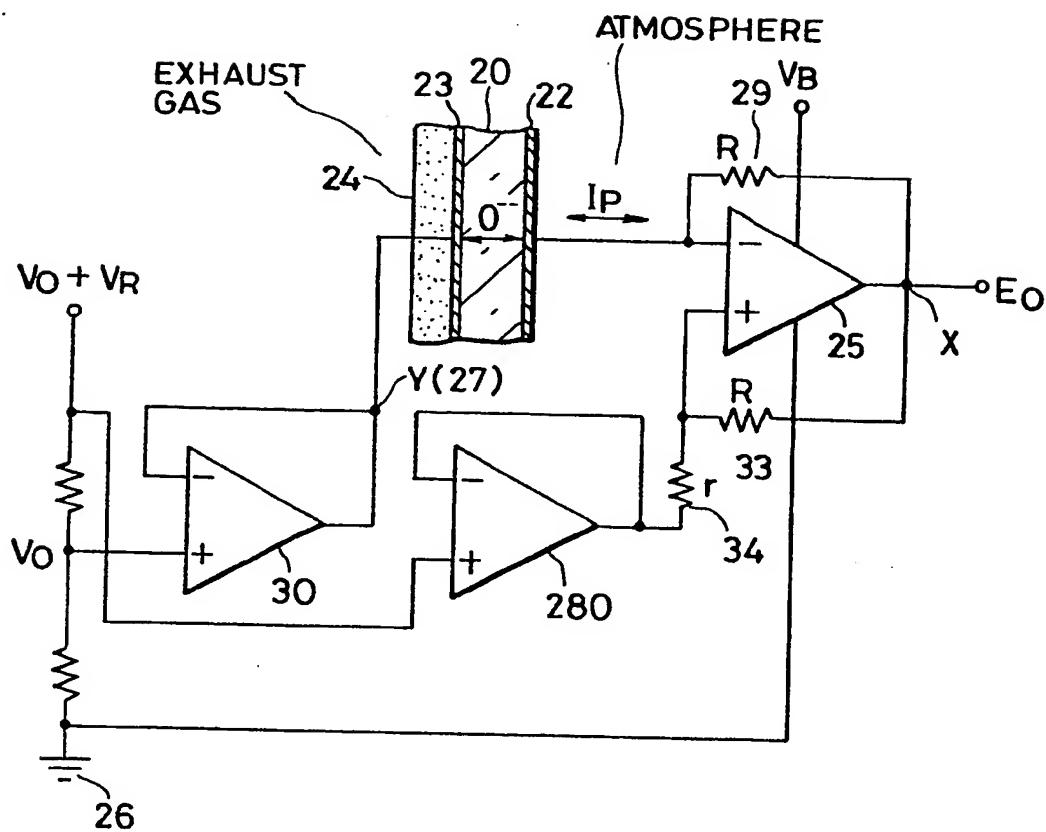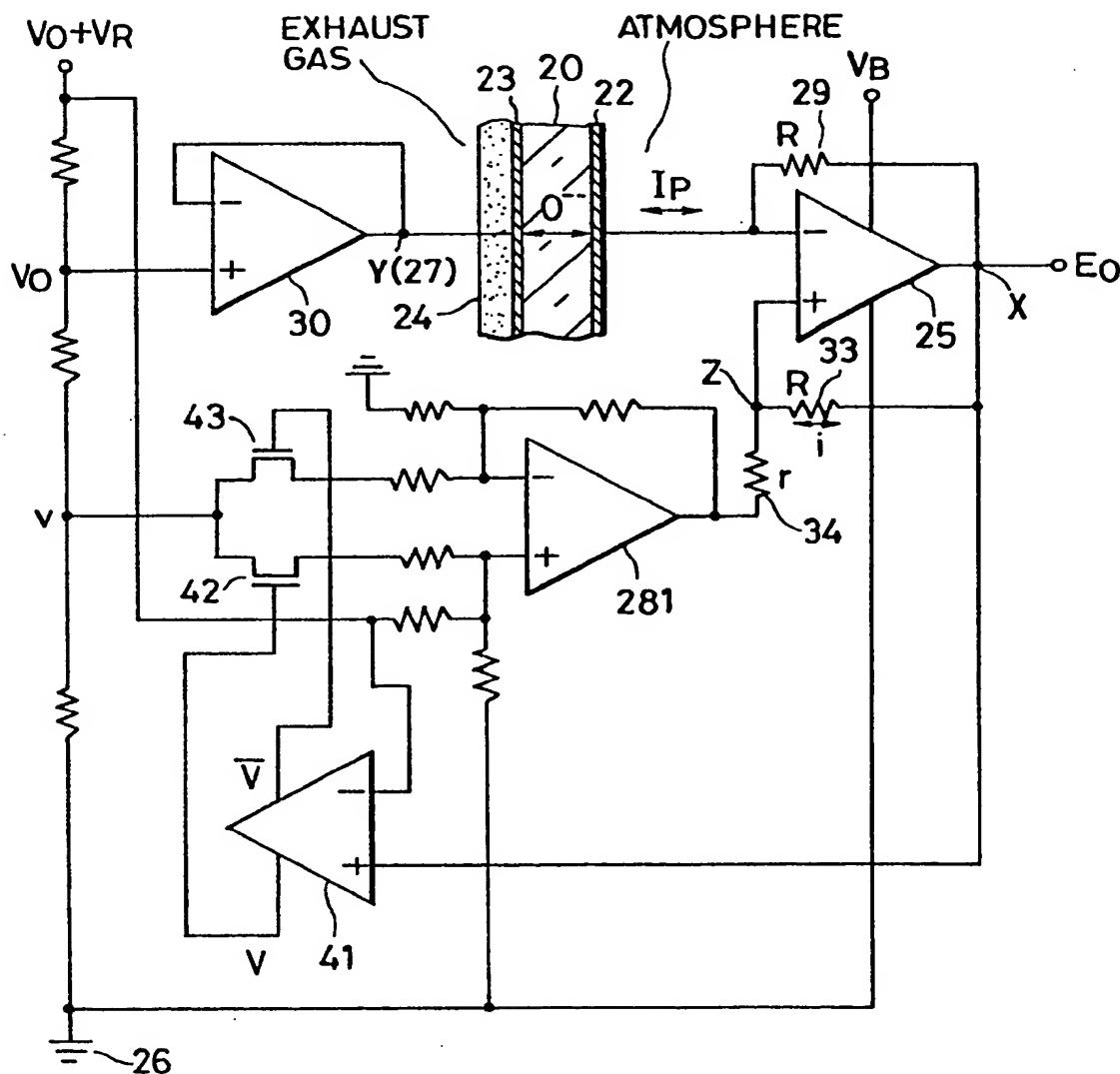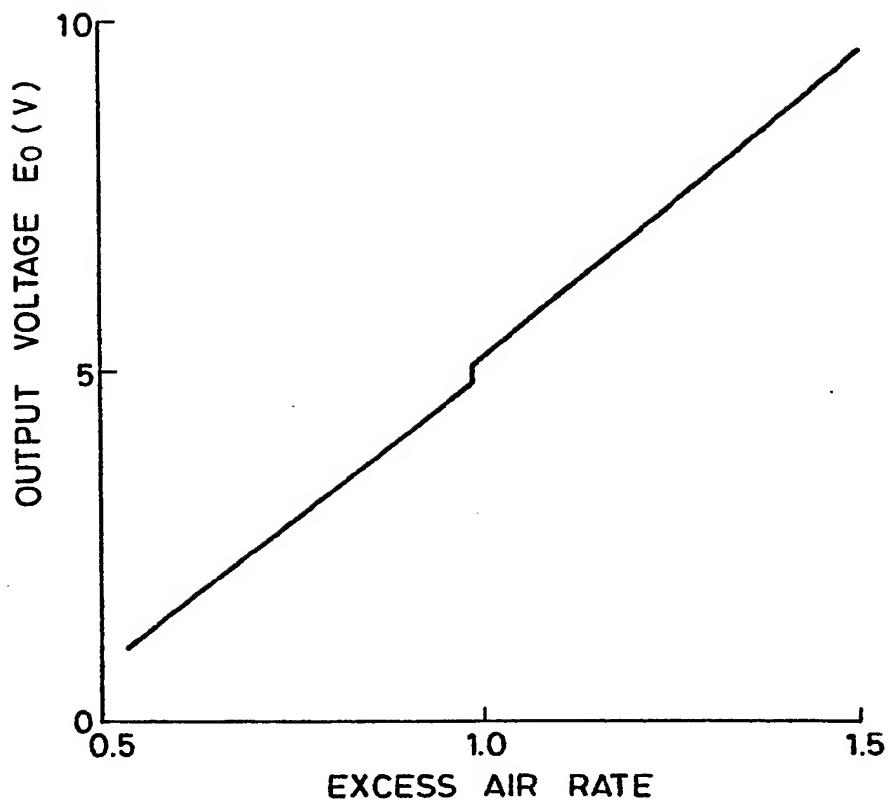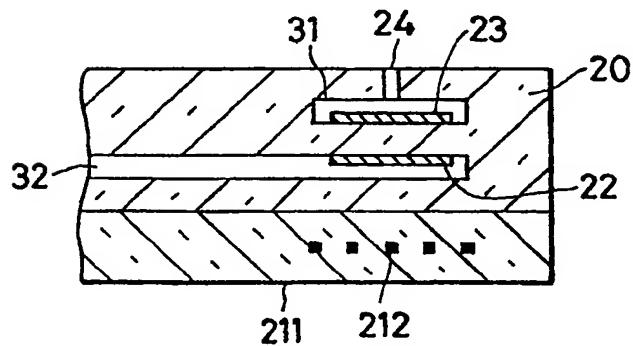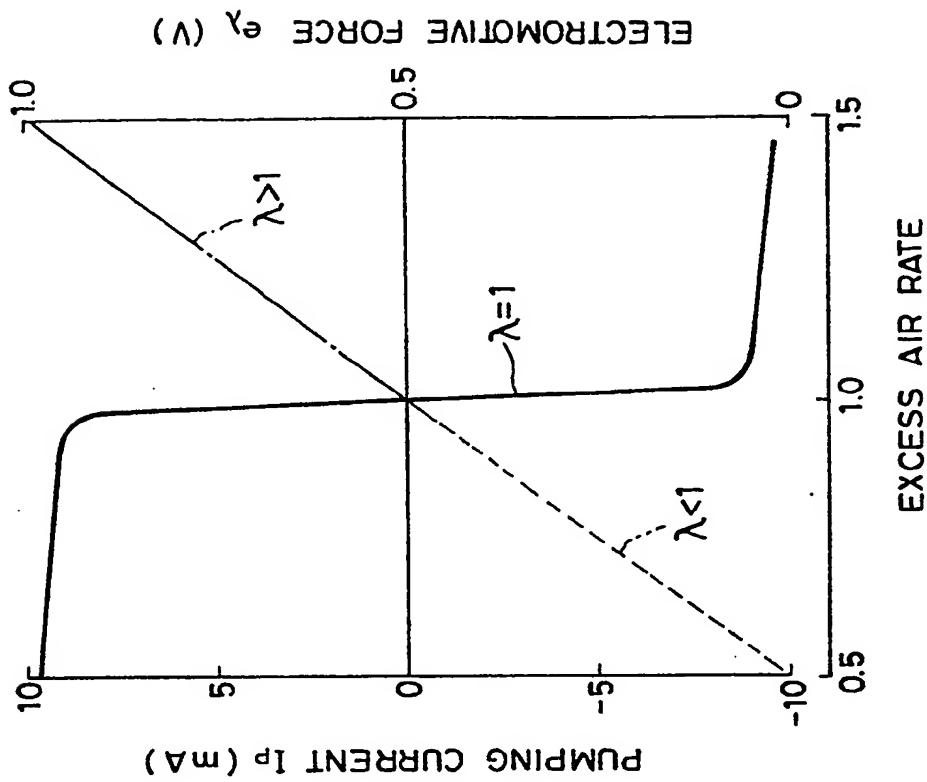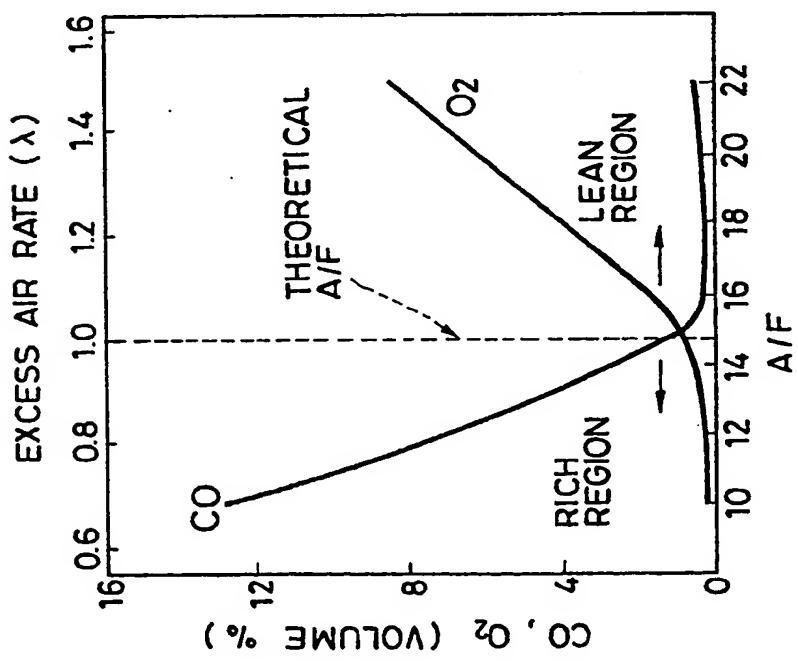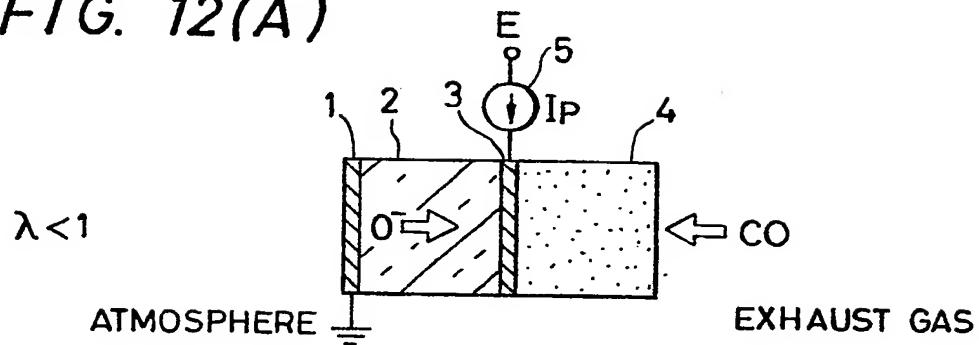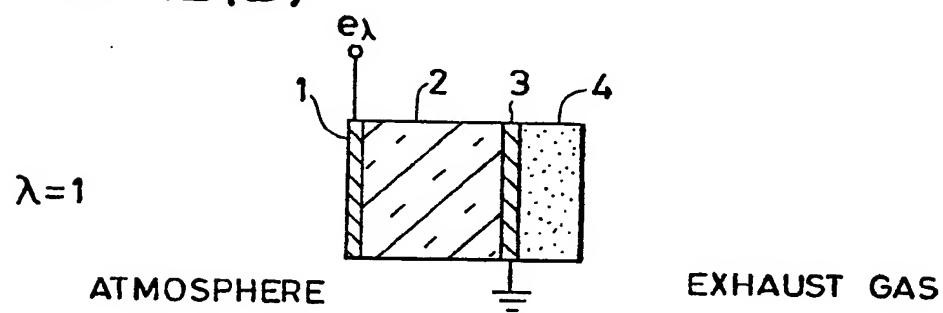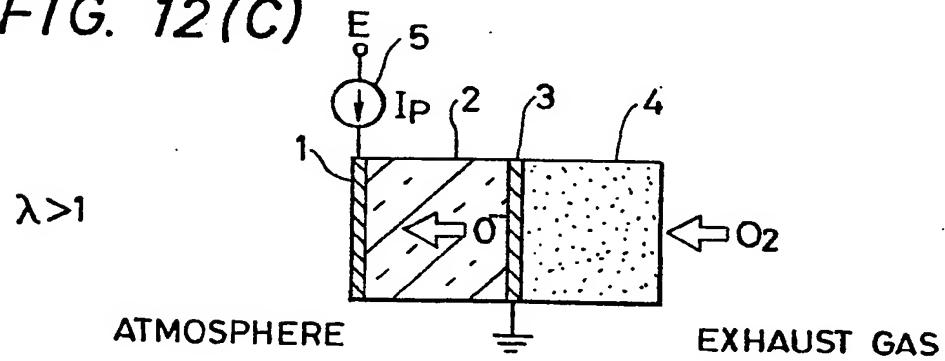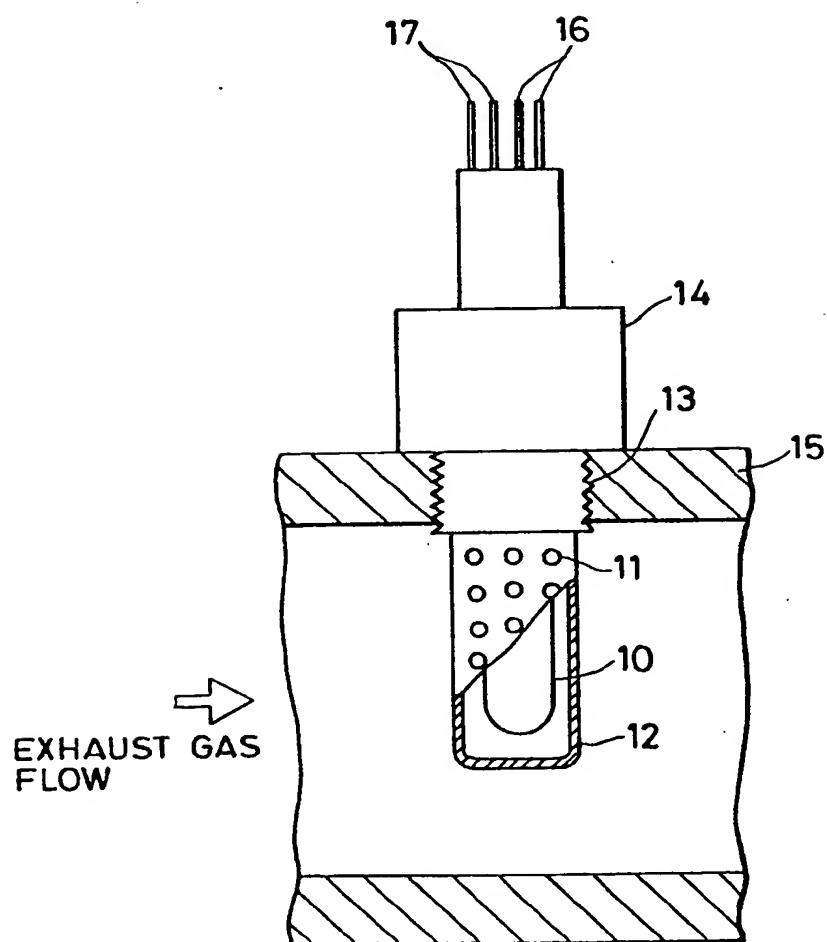
DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl 4)
Y	EP-A-0 082 372 (NISSAN MOTOR) * Page 1 - page 8, line 12 * ---	1-3	G 01 N 27/56
Y	GB-A-2 059 645 (NISSAN MOTOR) * Page 1 - page 3, line 50 * ---	1-3	
A	US-A-4 313 810 (H. NIWA) * Abstract; claims * ---	1-4	
A	GB-A-2 053 488 (NISSAN MOTOR) * Abstract; claims * -----	1-4	

TECHNICAL FIELDS SEARCHED (Int. Cl.4)

G 01 N 27/56

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	13-05-1986	CALLEWAERT-HAEZEBROU

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